Interferometric Imaging and Stellar Interferometry at JPL

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Why Interferometry?

1: Imaging resolution
  - $\lambda/\mathbf{B}$ for an interferometer vs. $\lambda/\mathbf{D}$ for a telescope
  - **B**, separation of apertures, can cost-effectively be made very large

2: Astrometric accuracy
  - Interferometers have a simple geometry which can be accurately monitored to minimize systematic errors
  - Interferometers use starlight efficiently

3: High dynamic range capability
  - Interferometers have the ability to “null starlight” with extreme precision
  - Allows detection of planets or other dim objects orbiting a star

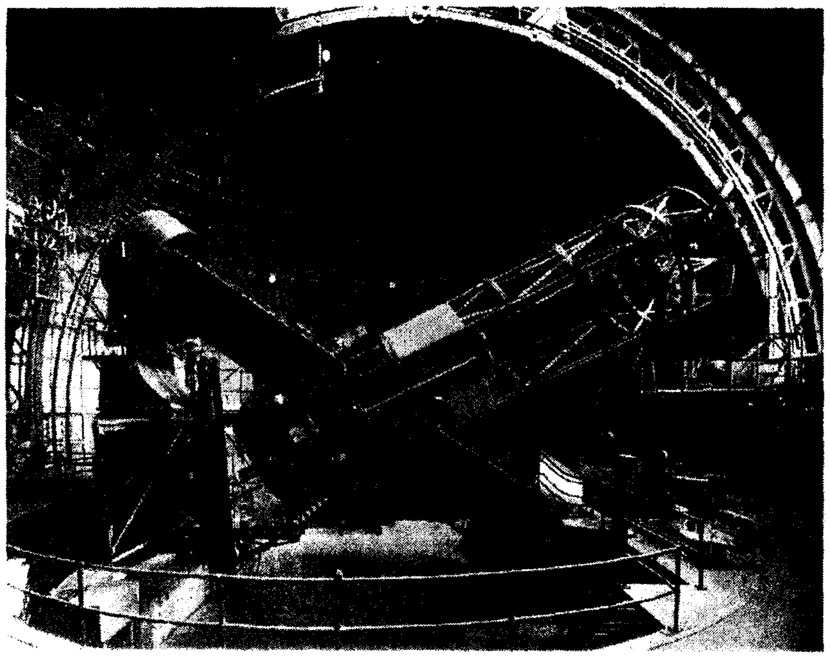


Figure 13.5 *The 100 inch (2.5 m) Hooker reflector on Mount Wilson, completed in 1917. (Courtesy* The Observatories of the Carnegie Institution of Washington.*)*

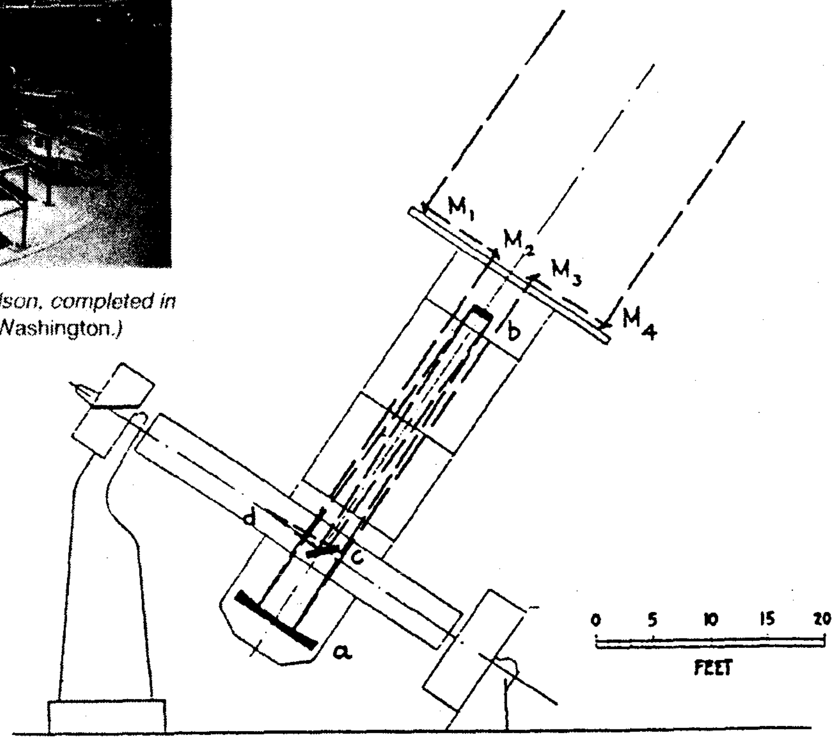
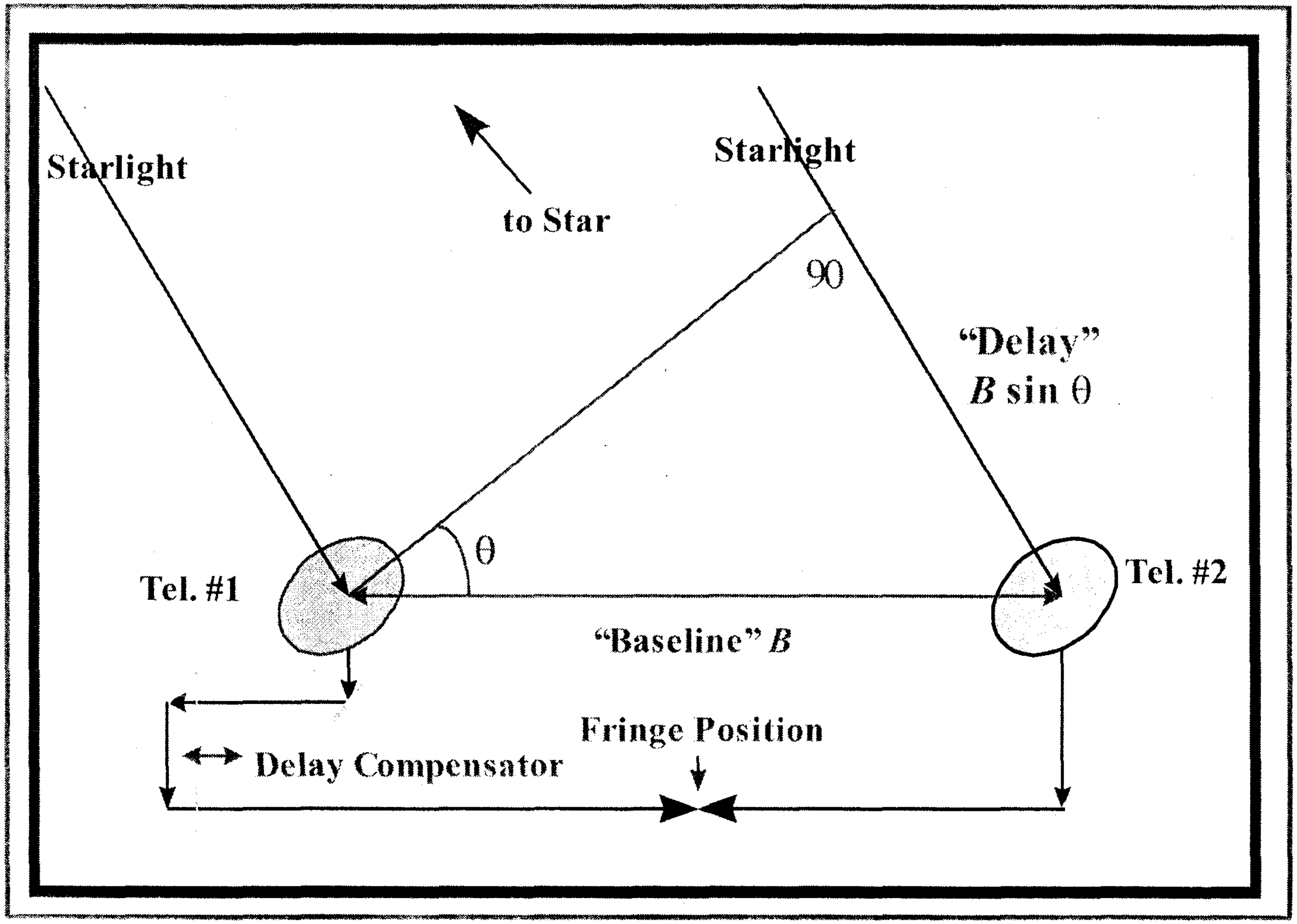
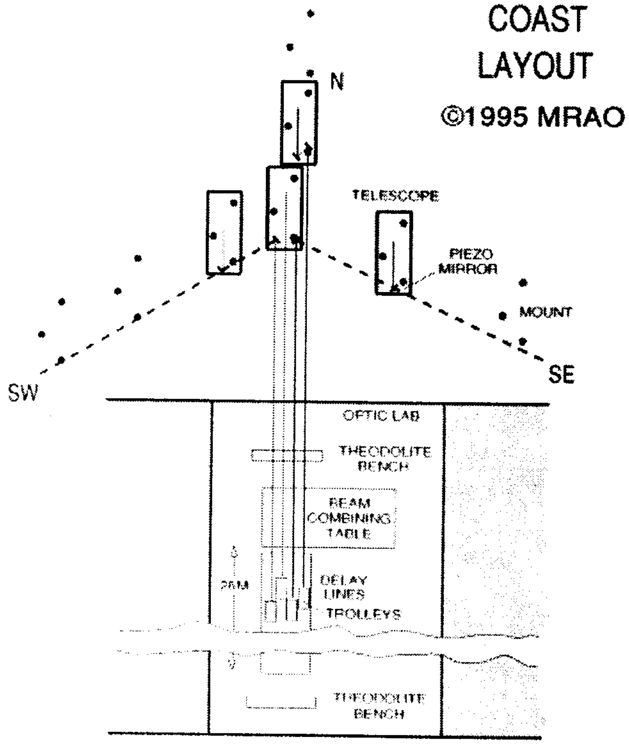


FIG. 1.—Diagram of optical path of interferometer pencils. M_1, M_2, M_3, M_4, mirrors; *a*, 100-inch paraboloid; *b*, convex mirror; *c*, coudé flat; *d*, focus.

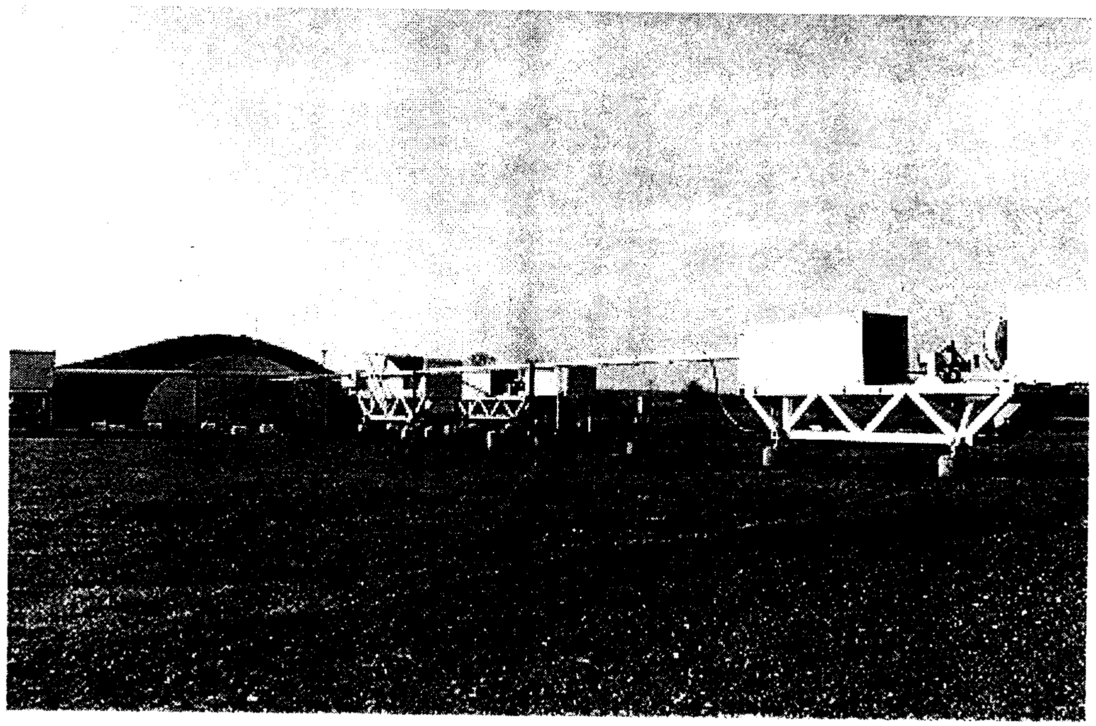
Simple Long-Baseline Stellar Interferometer



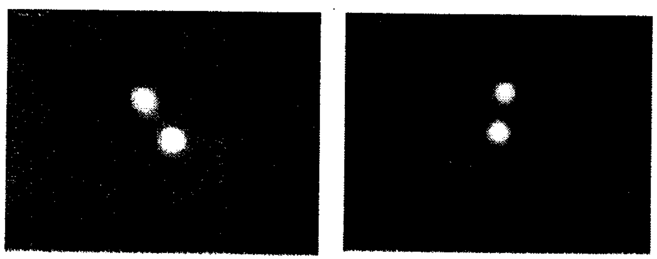
Optical Imaging through Stellar Interferometry



Cambridge Optical Aperture Synthesis Telescope (COAST)

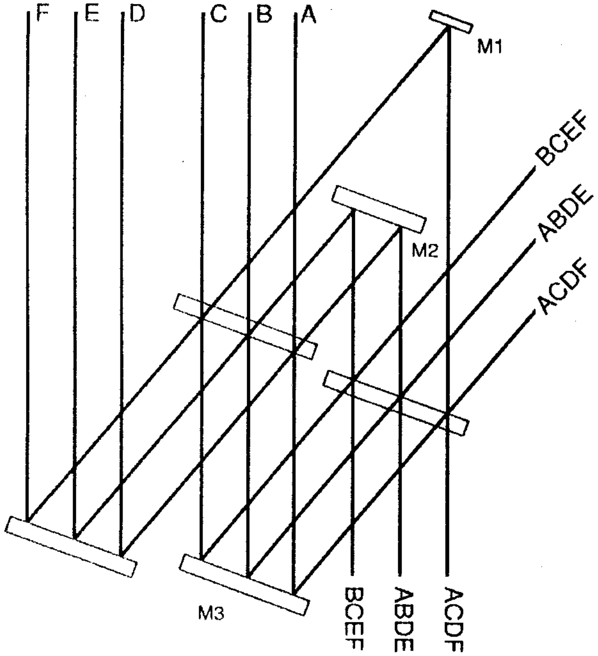


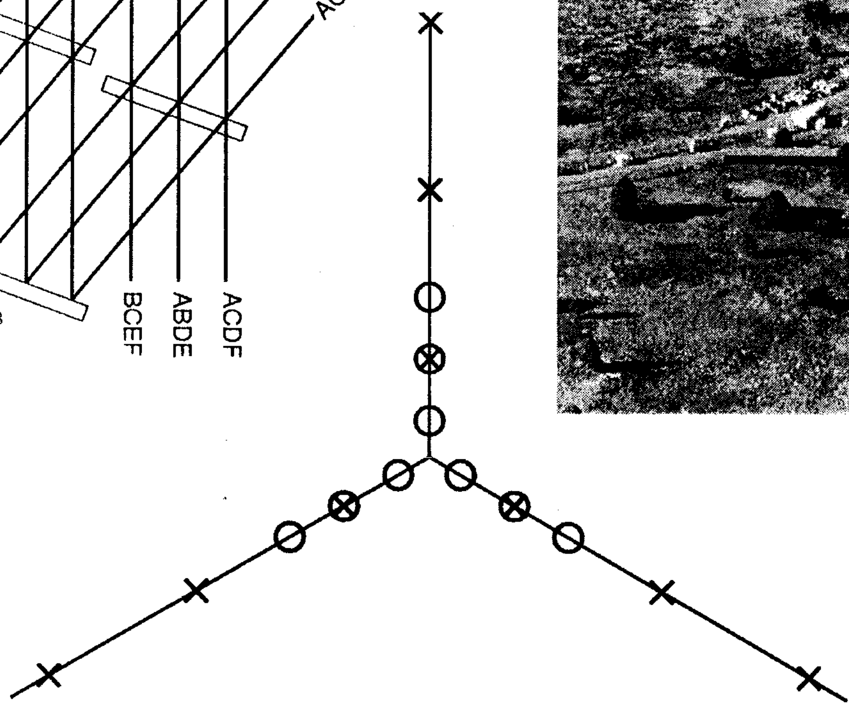
Optical Synthesis Images of Capella

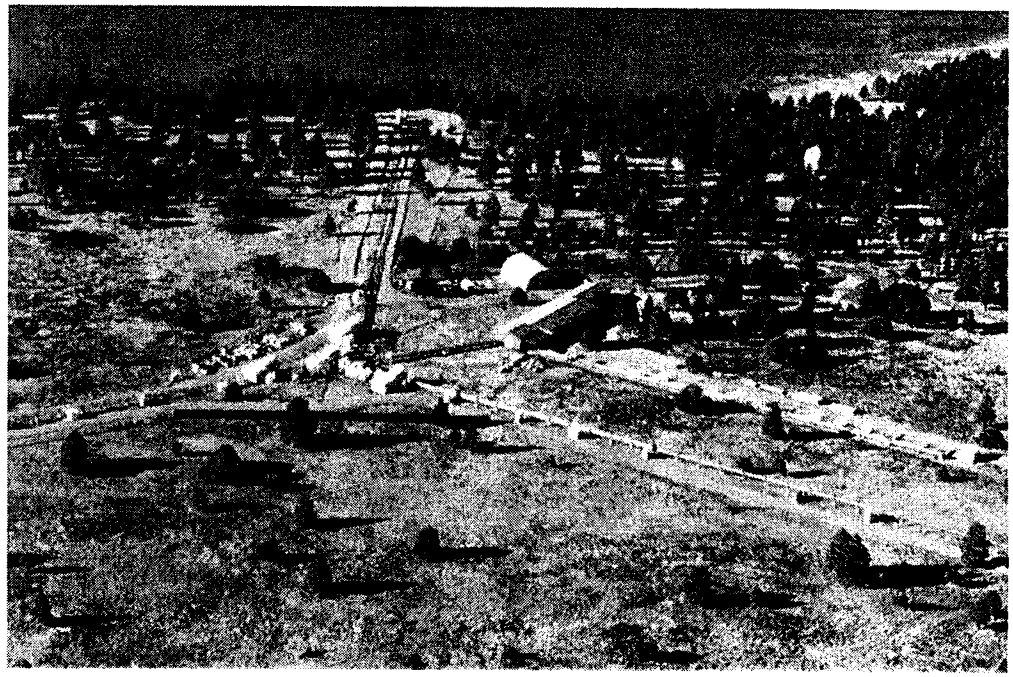


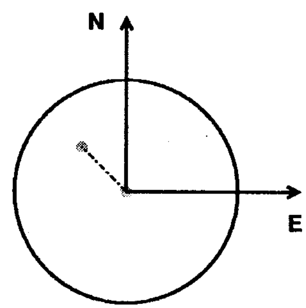
13 Sept. 1995 **28 Sept. 1995**

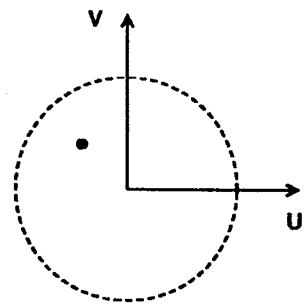
Beam Combination for Synthesis Imaging



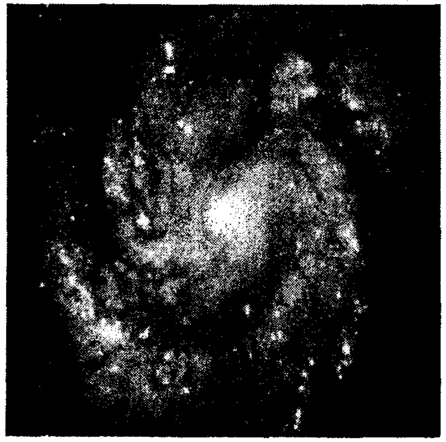






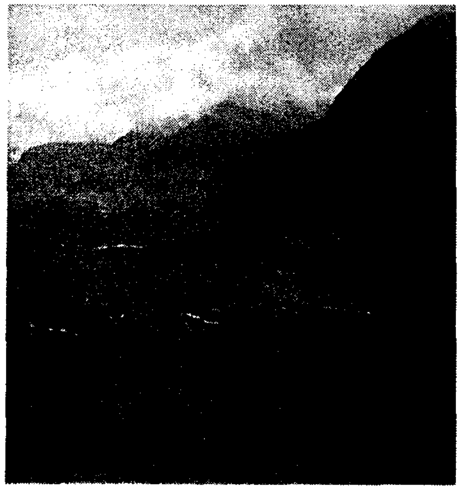


NASA's Astronomical Search for Origins



To understand how galaxies formed in the early universe and to determine the role of galaxies in the appearance of stars, planetary systems and life.

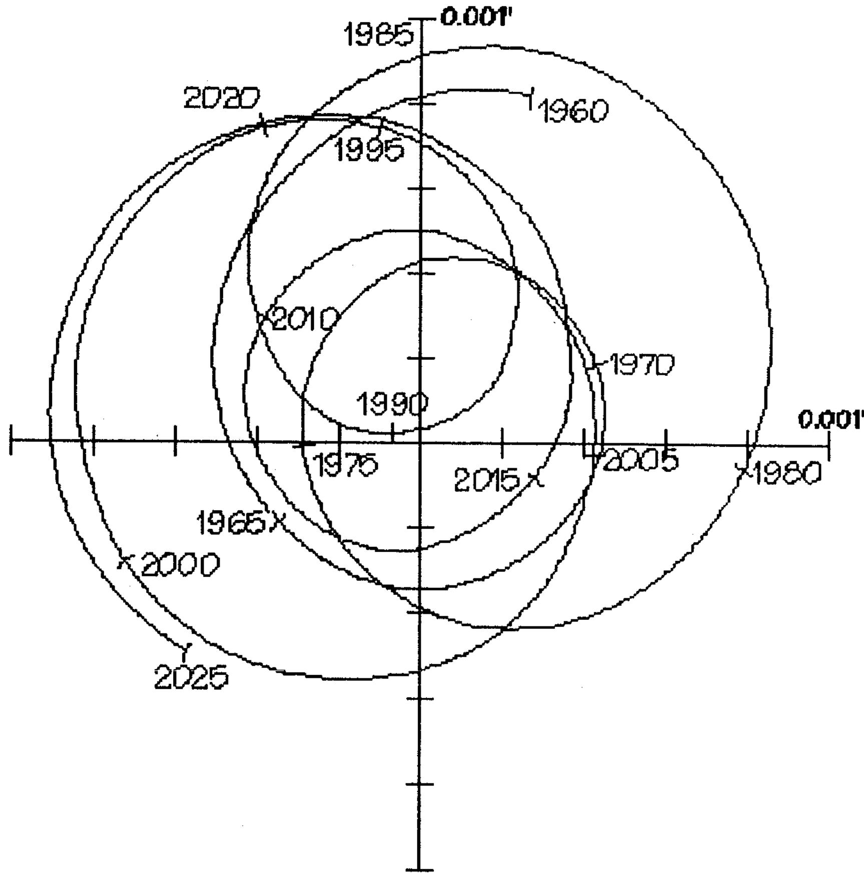
To understand how stars and planetary systems form and to determine whether life-sustaining planets exist around other stars.



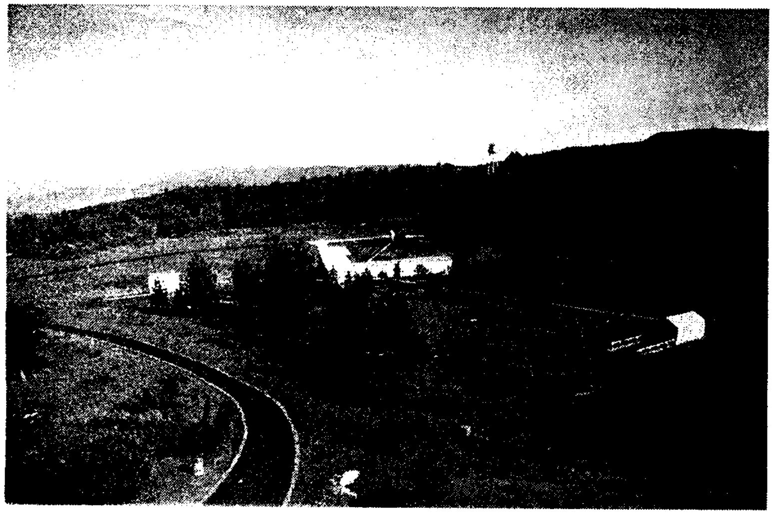
To understand how life originated on Earth and to determine if it began and may still exist elsewhere as well.

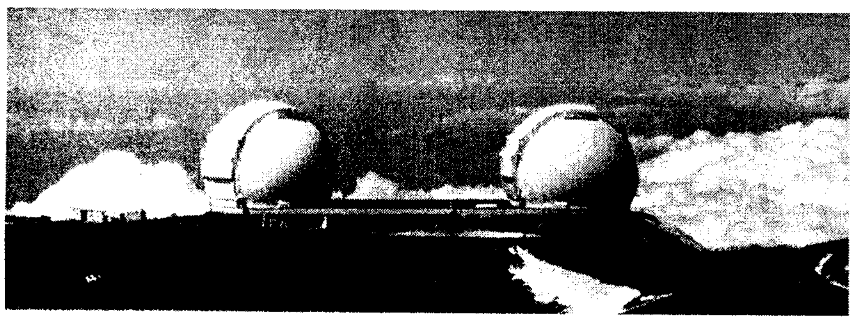
Astrometric Search for Planets

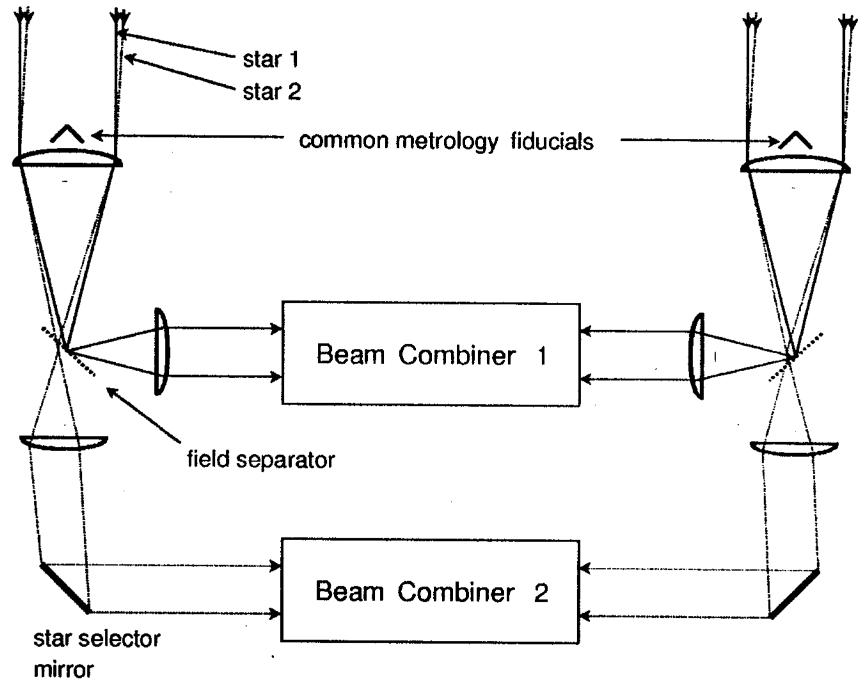
- Astrometry measures positional wobble due to planets
  - More sensitive than RV
  - no sin(i) ambiguity
- Interferometry will enable measurements at the micro-arcsecond level
  - Earth at 10 pc produces 0.3 μas amplitude
- Result of new observing systems will be a census of planets down to a few M_{earth} over the next 10-20 years



Narrow Angle Astrometry



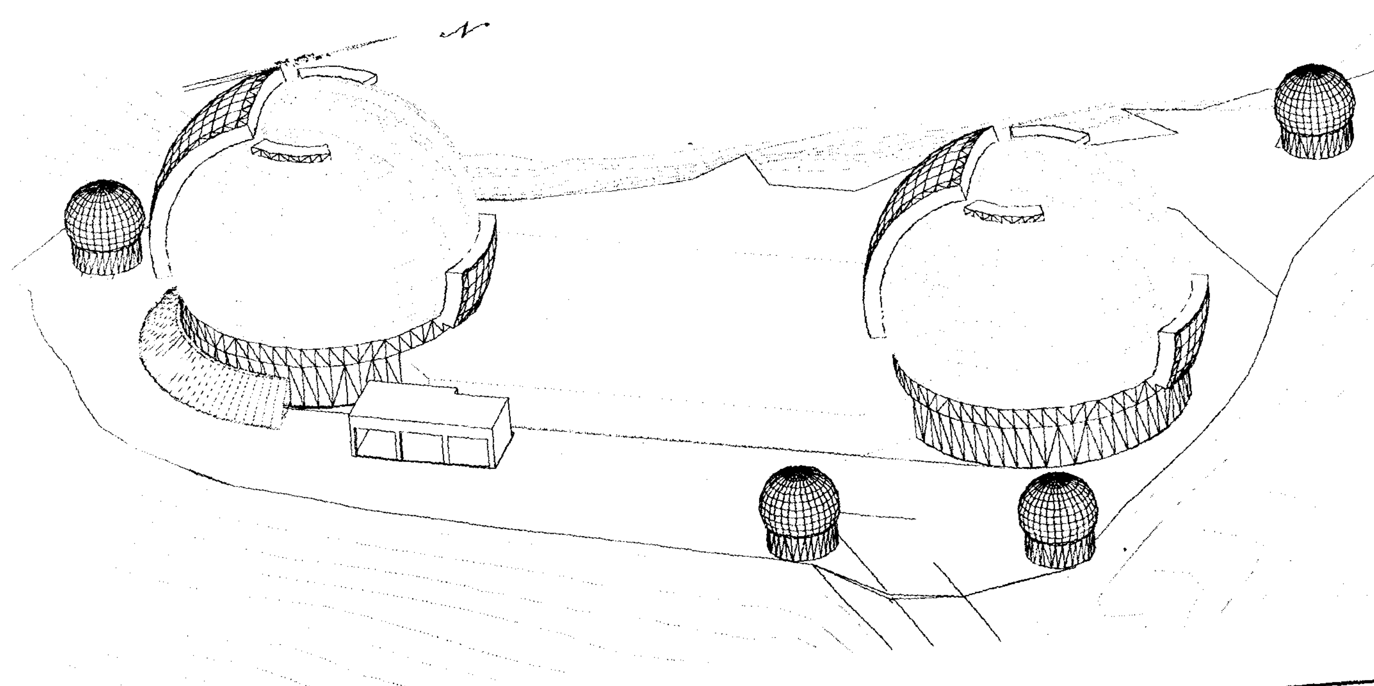




- Planet detection: "Jupiter" at 10 pc produces a 1 mas peak-to-peak star wobble.
- 20 μas astrometry possible from the ground over narrow angles.

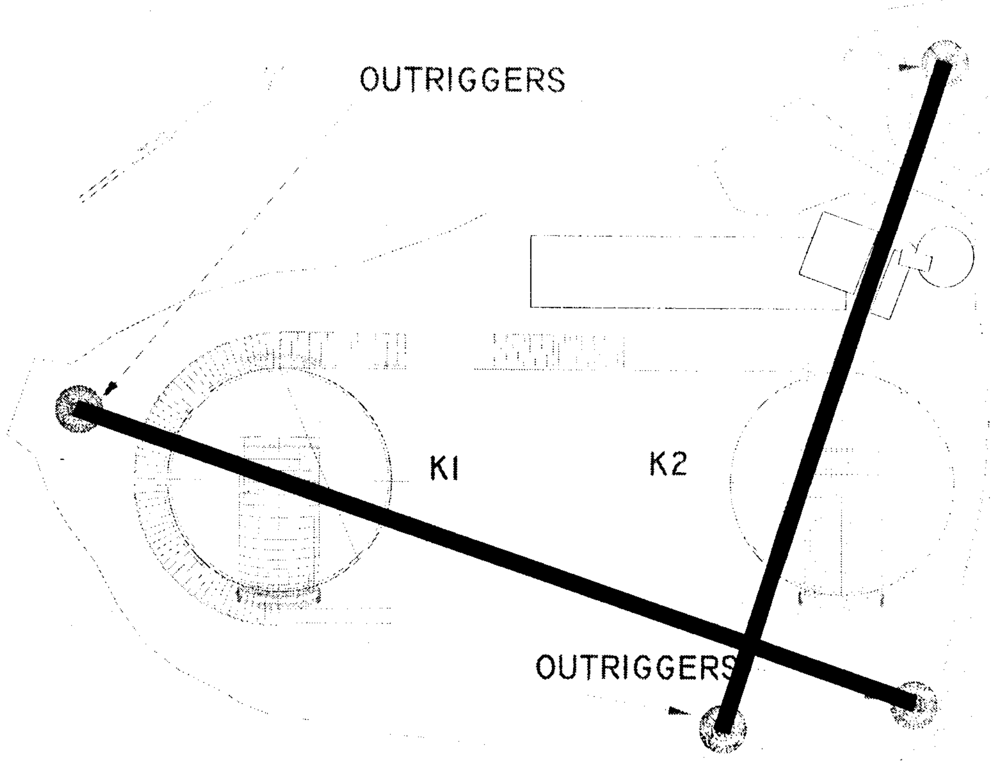
Keck Interferometer

- Interferometry with the two 10-m Keck telescopes and four 1.8-m outrigger telescopes
- Funding from NASA as part of the Origins Program
- Joint development between JPL and CARA
- Funding started in Oct 1997 (FY98); CDR: Aug '98



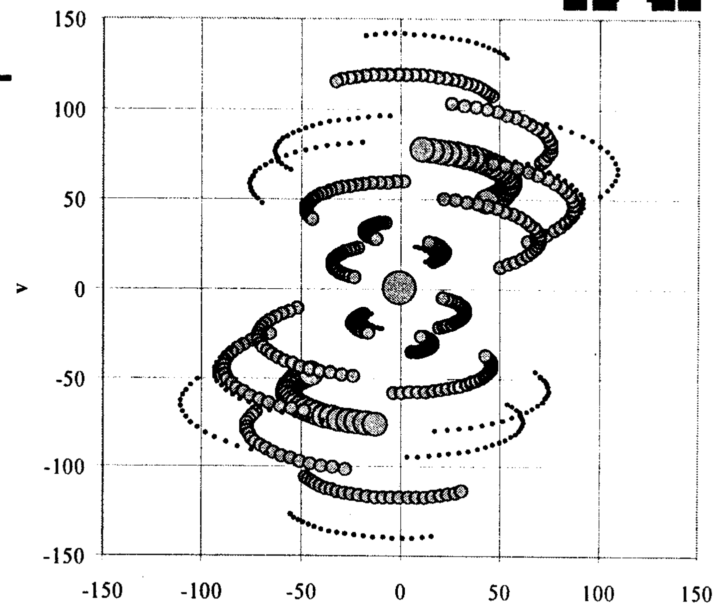
Astrometric Detection of Exoplanets

- Science objective
  - Survey 100's of nearby stars for planets to Uranus mass
  - Uses outrigger telescopes for long-term survey
- Approach
  - High-accuracy narrow-angle astrometry
- Configuration
  - 4 1.8-m outriggers
  - Orthogonal >100m baselines
  - Dual-star feeds
  - End-to-end laser metrology
  - 30 μas per hour accuracy for differential astrometry
    - Uses K17 isoplanatic ref.



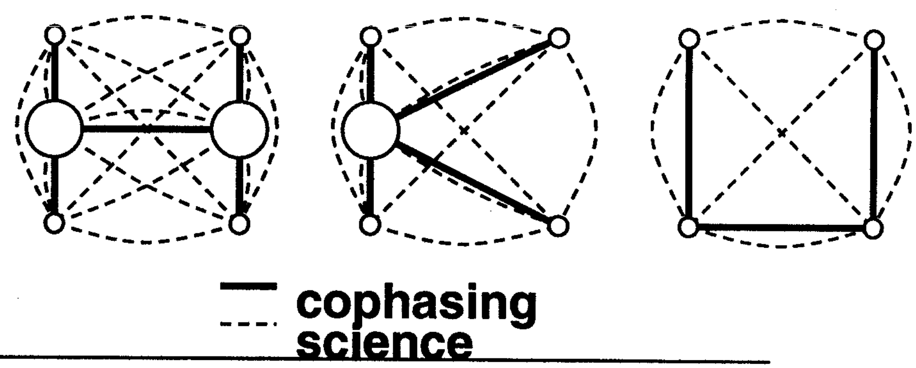
Imaging

- Imaging with 6-element array
- Good (u,v)-plane coverage
- 9 of 15 baselines include a 10-m telescope
  - Background-limited sensitivity equivalent to two 4.4-m's
  - Other imaging options using OTs with 1 or 0 Kecks
- Use cophasing to increase sensitivity
- Ultimate sensitivity
  - K-K fringe tracking: K14.1
  - OT-OT fringe tracking: K10.8
  - Cophased imaging
    - K19 for SNR >10 in 1000 s on a Keck-OT baseline
    - Requires K11.6 isoplanatic ref

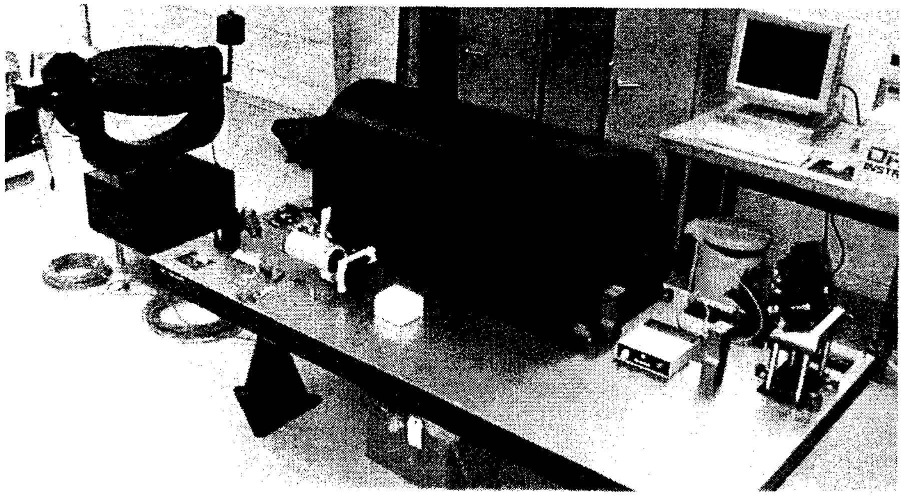


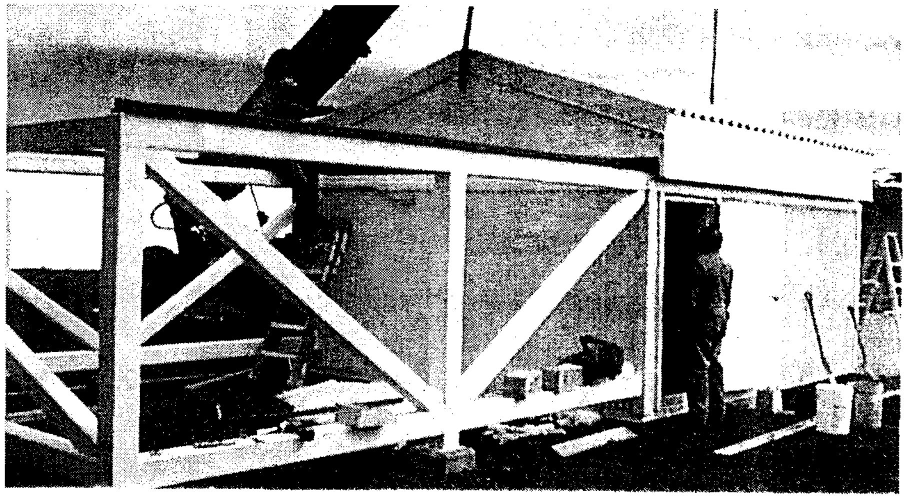
u,v coverage with outriggers and Kecks
(width of line indicates baseline)

Science and cophasing baselines

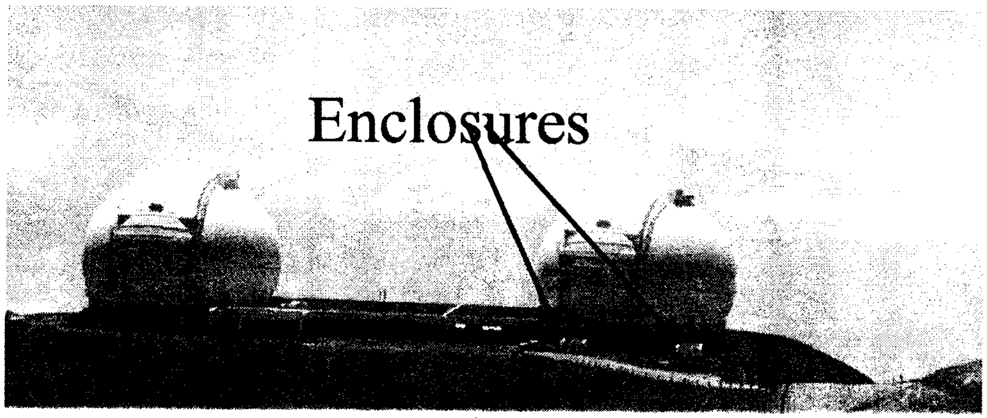


Siderostats

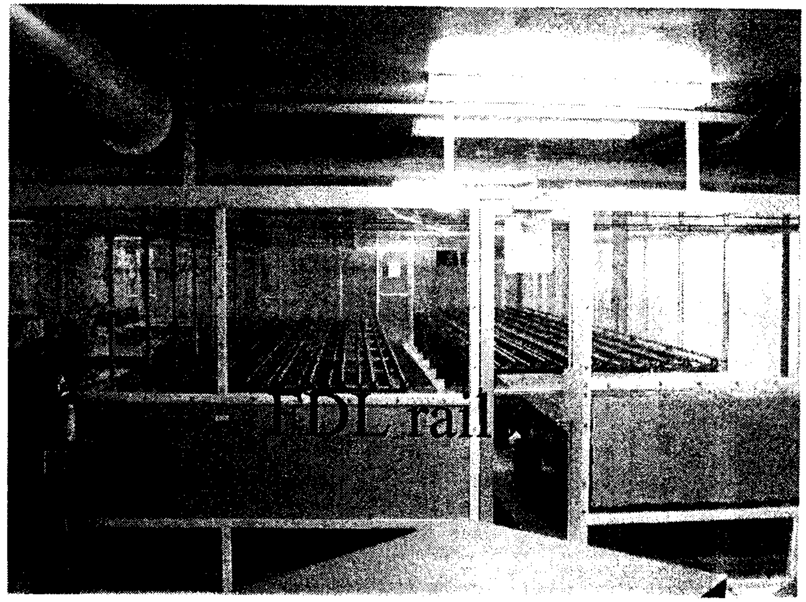


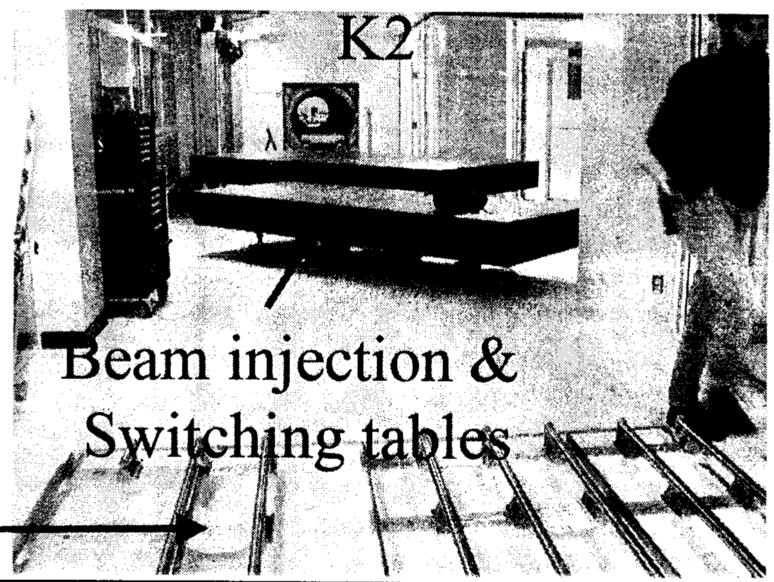


- Siderostats installed & operational on summit
- Beam transport mirrors aligned & star acquired in basement



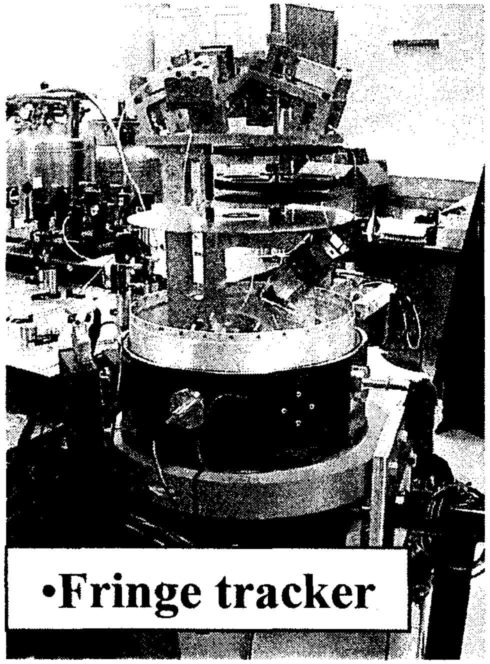
Basement Infrastructure Installation

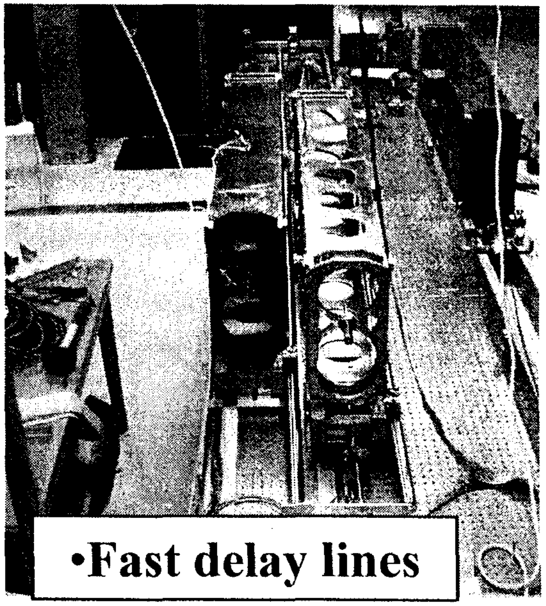


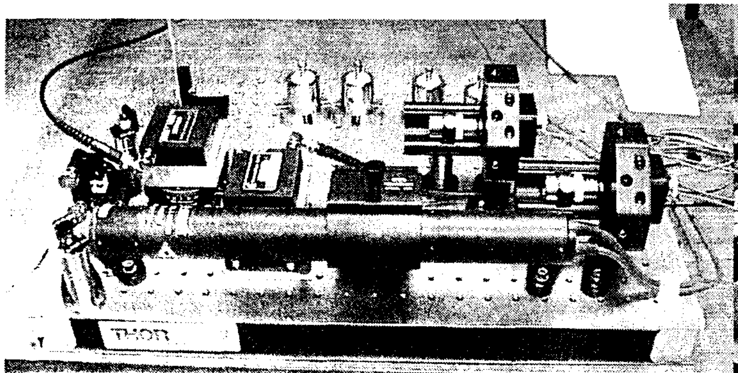


Hardware

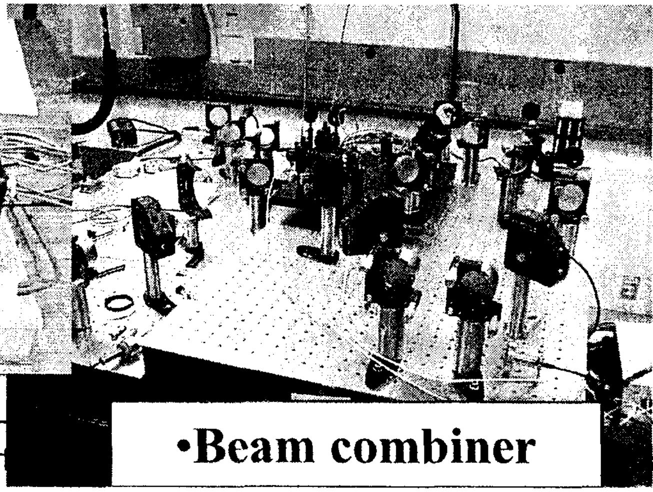

•Long delay lines

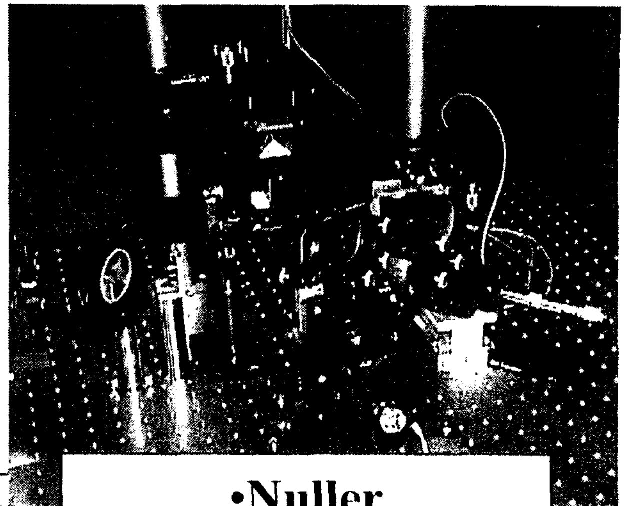

•Fringe tracker

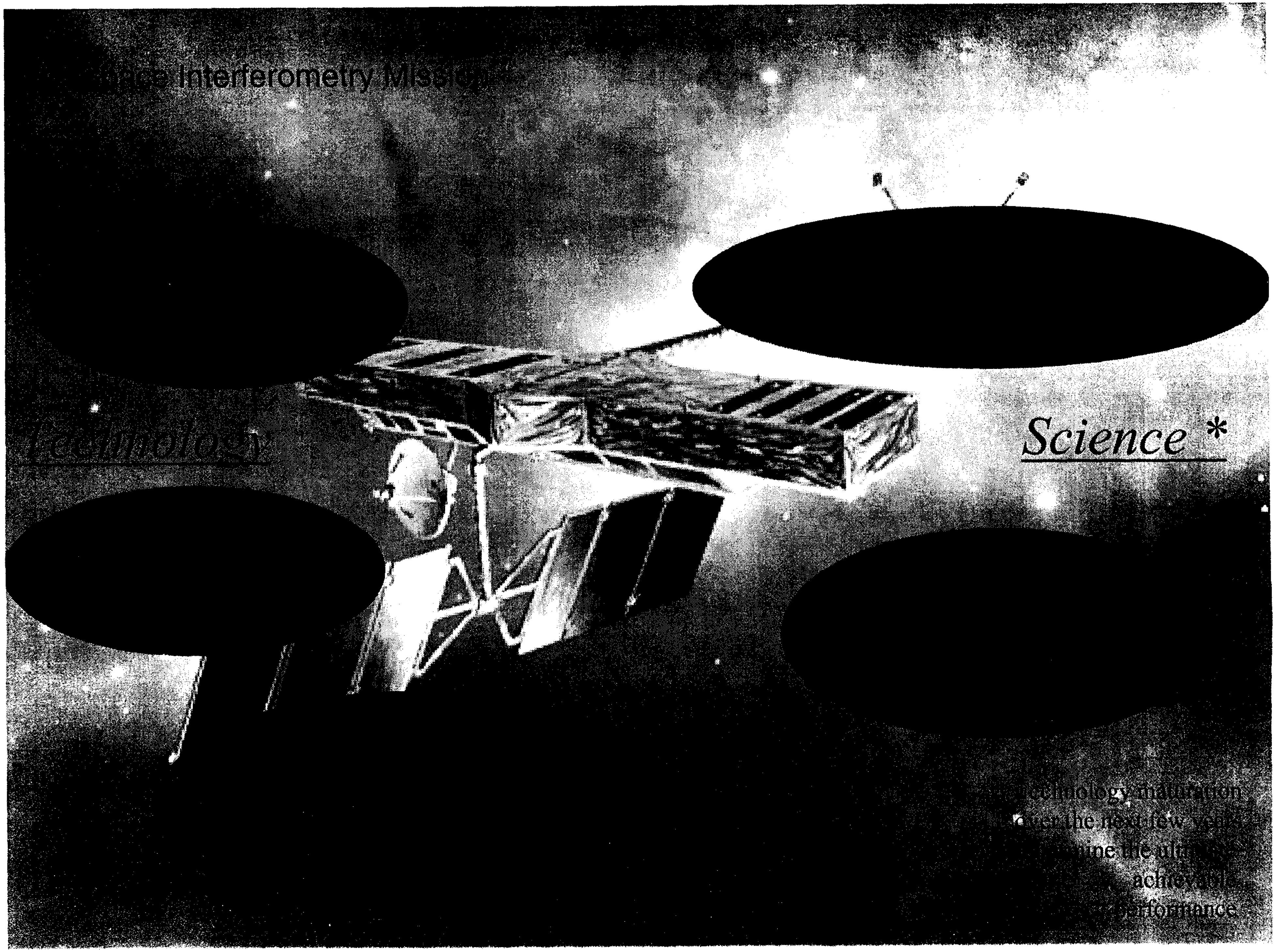

•Fast delay lines



•Laser metrology

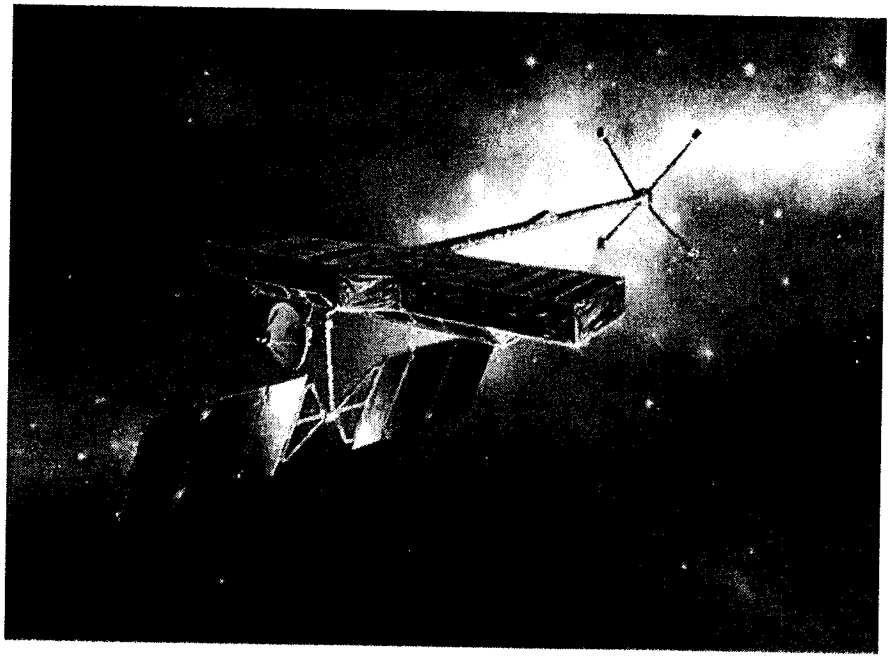

•Beam combiner


•Nuller



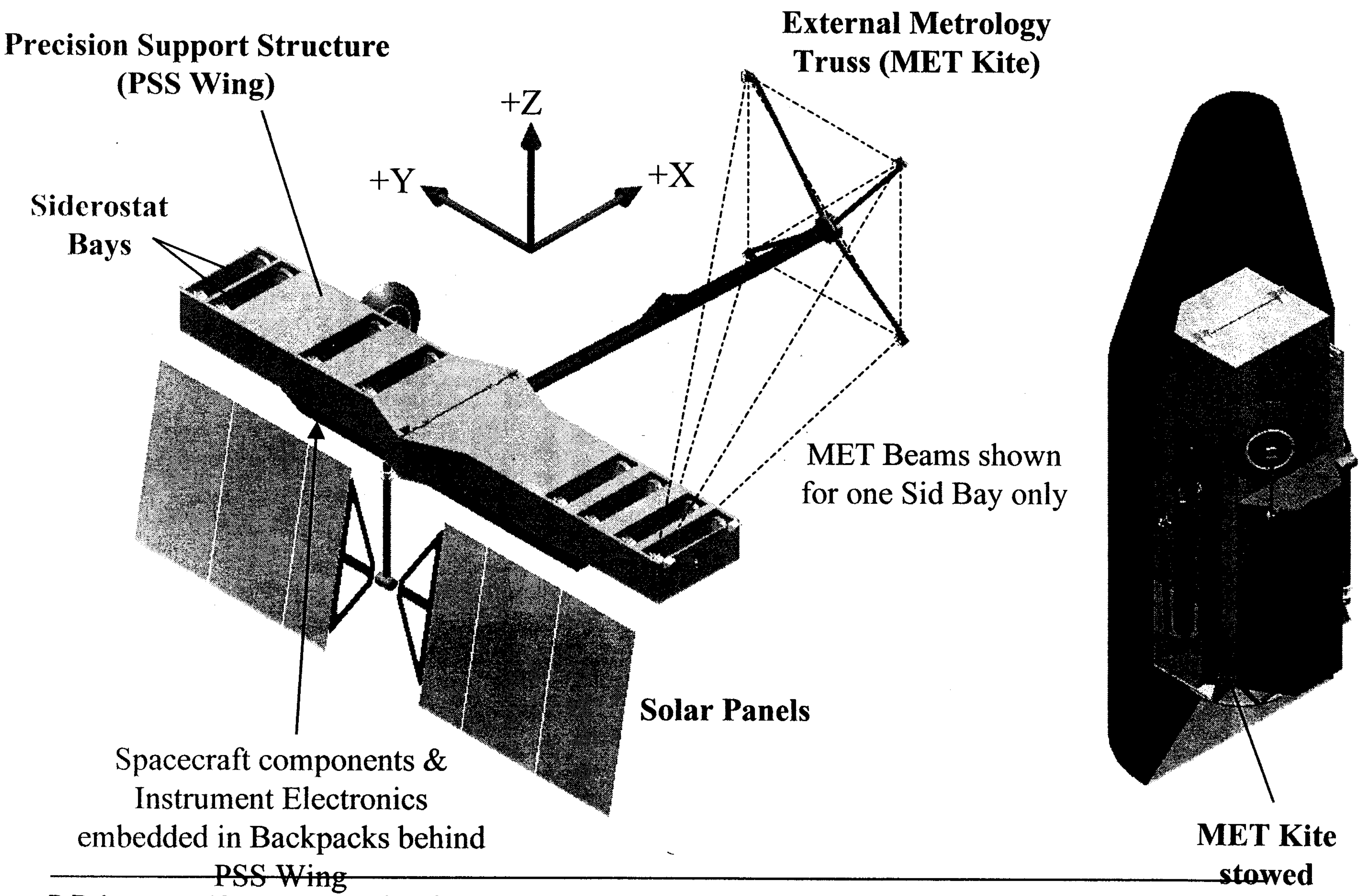
Interferometry
Technology
Science *
technology maturation
over the next few years
achievable
performance

Space Interferometry Mission (SIM)

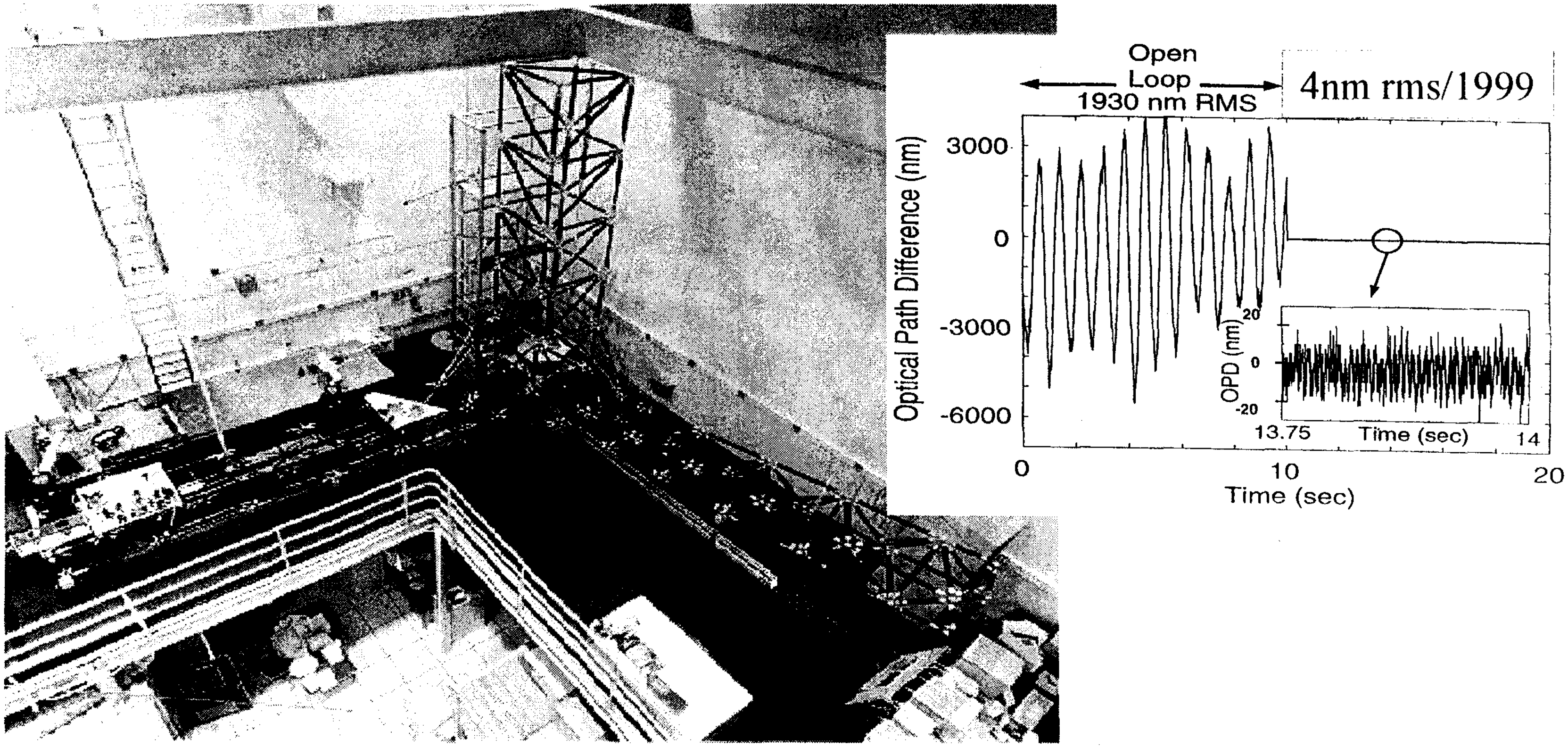


Wide angle astrometric accuracy	4 μas (5 yr)
Narrow angle astrometic accuracy	1 μas (1 hr)
Instrument field of regard	15 degrees
Instrument throughput (V=16 star)	5.8 μas (10 min)
Synthesis Imaging Resolution	10 mas
Nulling Depth	10^{-4}

SIM Configuration

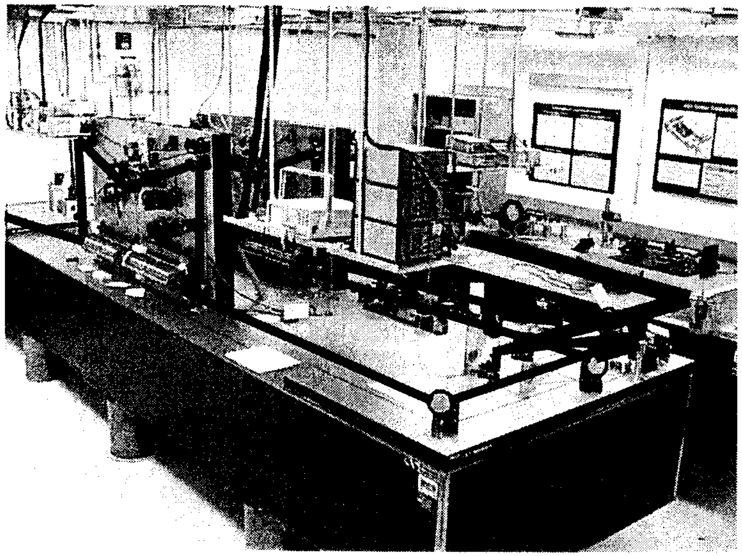


Nanometer Control Testbed



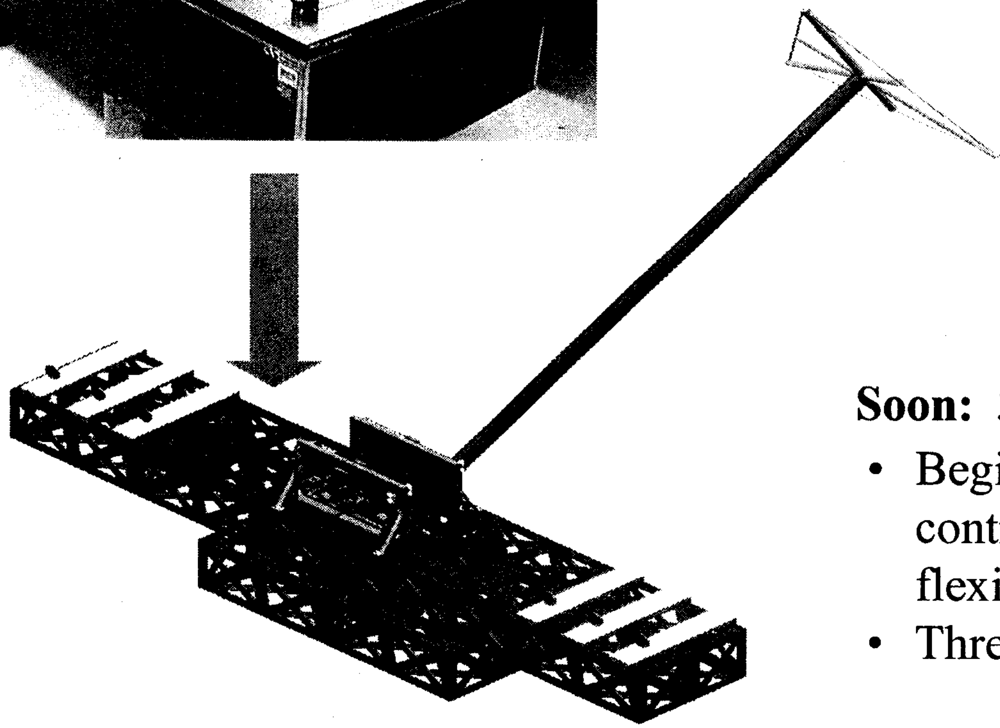
Flexible truss ~5 hz resonance
Simulated spacecraft disturbance (reaction wheels)
Active isolation of disturbance & active optical loop
(using laser interferometry as the sensor)

SIM System Testbed (STB-3)



Now: 3 baselines on optical table

- Three interferometers functioning on an optical table
- Completed detailed design of SIM-scale flexible structure to be built and installed by end-2000

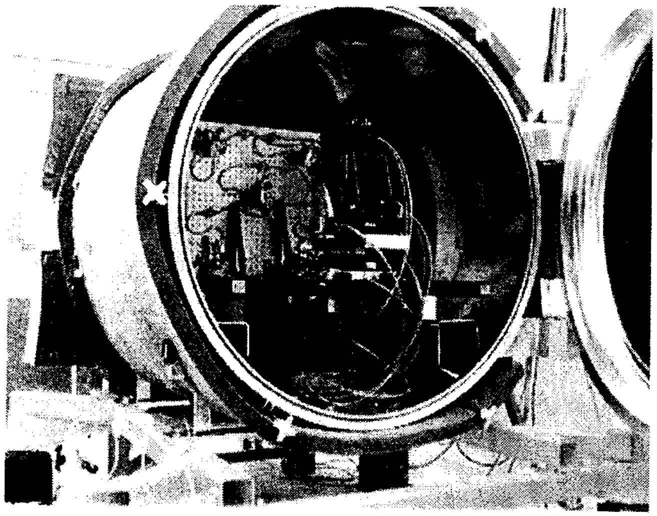


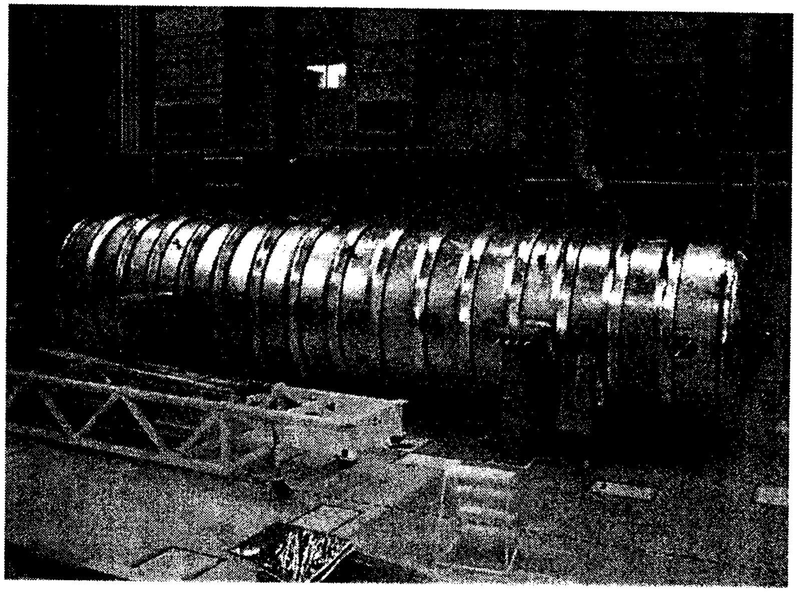
Soon: 3 baselines on structure

- Begin nanometer active control experiments on flexible structure
- Three baselines, full scale

Picometer measurement technology

Component technologies
- *superprecise optical elements*
- *picometer laser gauges*
- *frequency stabilized lasers*

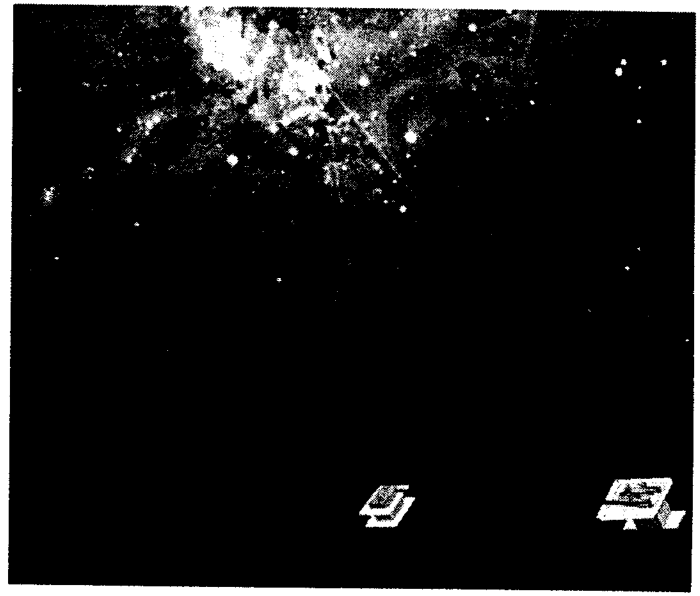


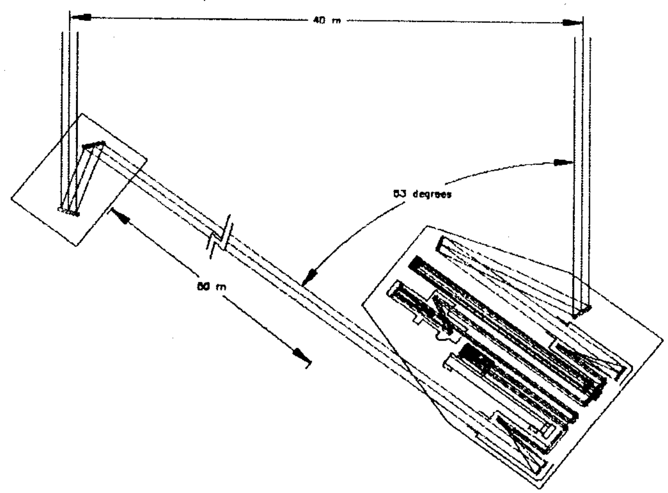


Microarcsec Metrology Testbed
- *fully functional interferometer tested in vacuum at picometer levels*
- *verify testing procedure for flight hardware*

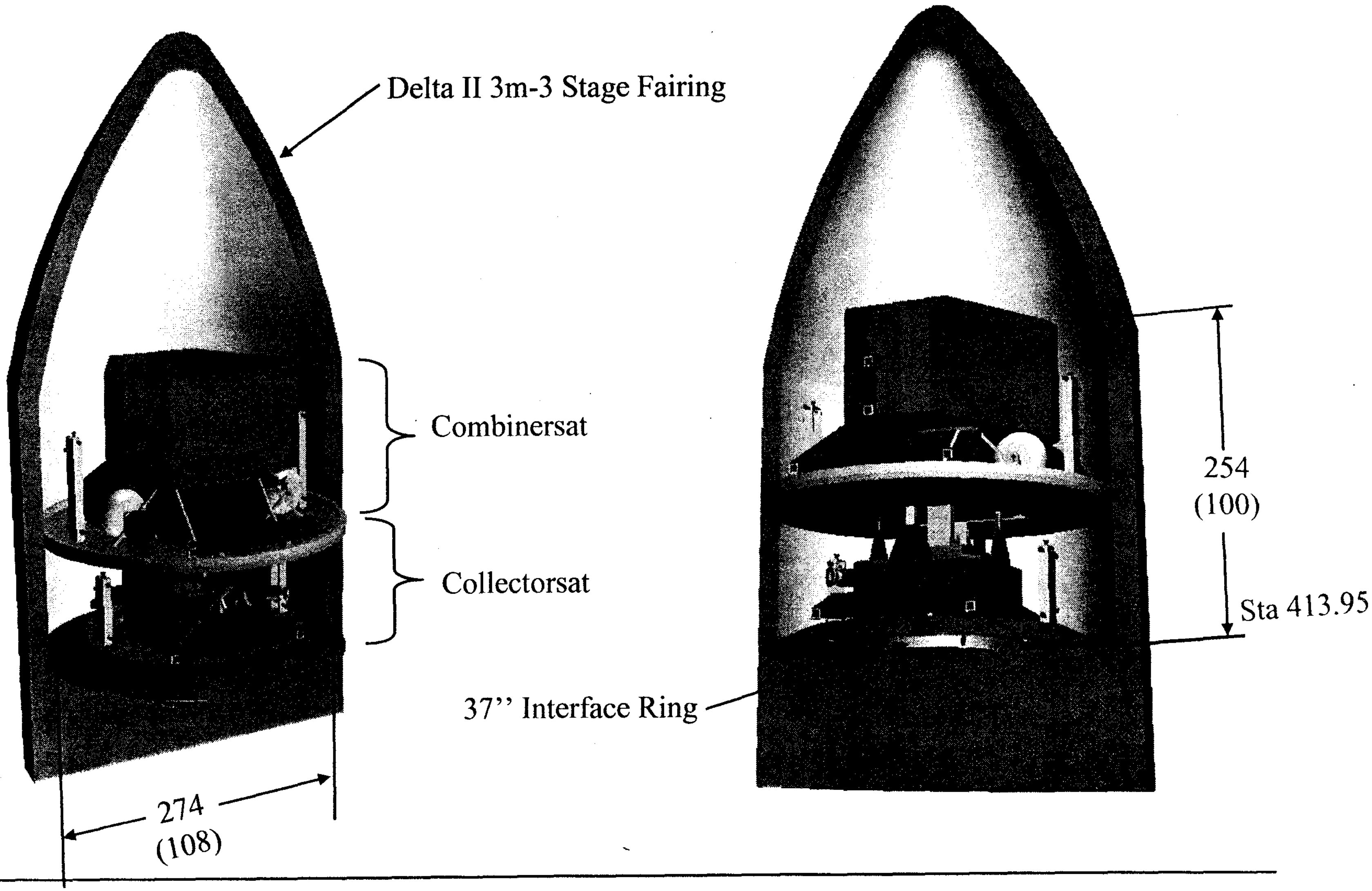
Multiple Spacecraft Interferometry
ST-3 Technology Mission

- The New Millennium Program ST-3 Mission will provide validation of key enabling technologies for TPF
  - Separated S/C interferometry
  - Precision formation flying
  - Real-time optical control of a separated S/C interferometer
  - Angular and linear metrology
  - Inertial referencing for phasing and guiding
  - Separated S/C interferometer I&T techniques

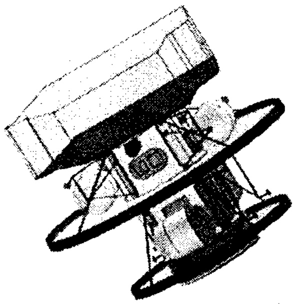




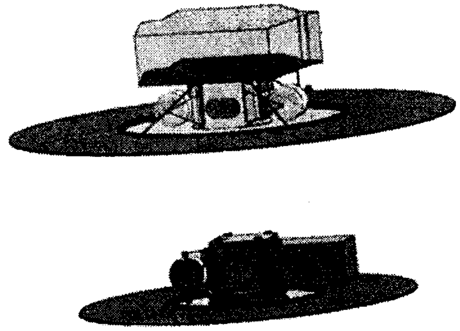
ST3 Launch Stack Configuration



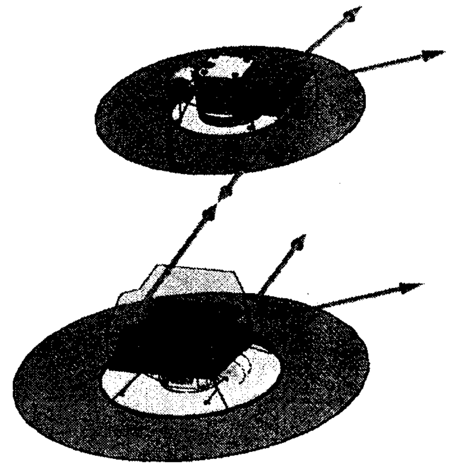
Mission Timeline

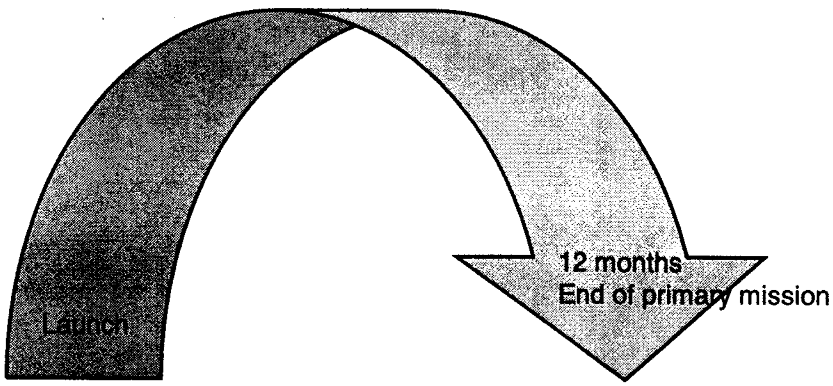


Cluster checkout

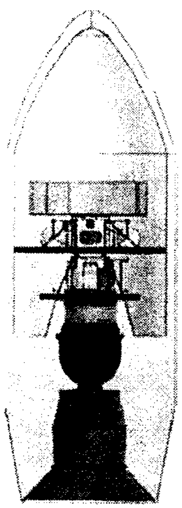


S/C separate and perform formation flying checkout & experiments
Combiner mode interferometry checkout, experiment & observations



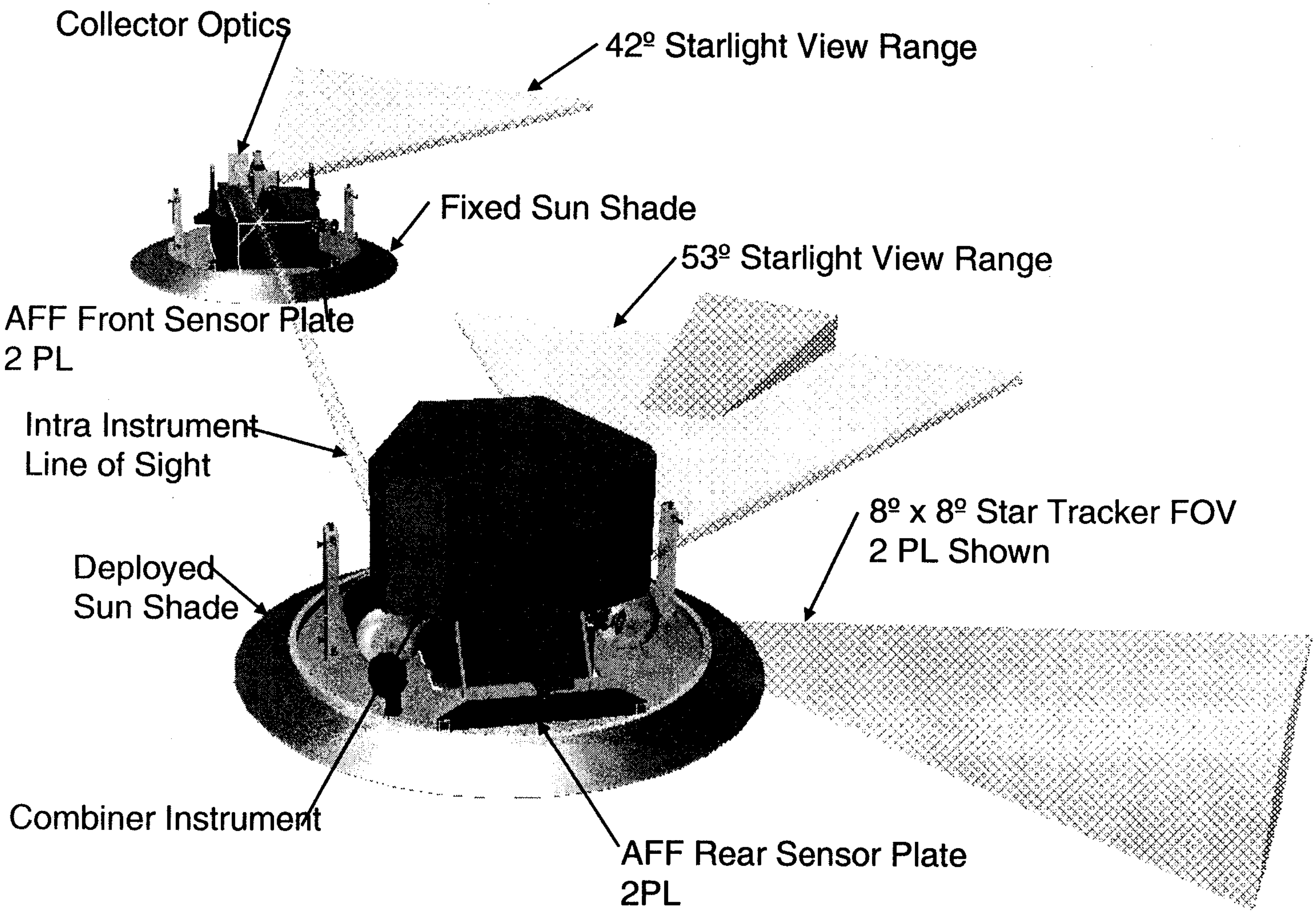


Separated spacecraft interferometry checkout experiments & observations
Formation flying experiments

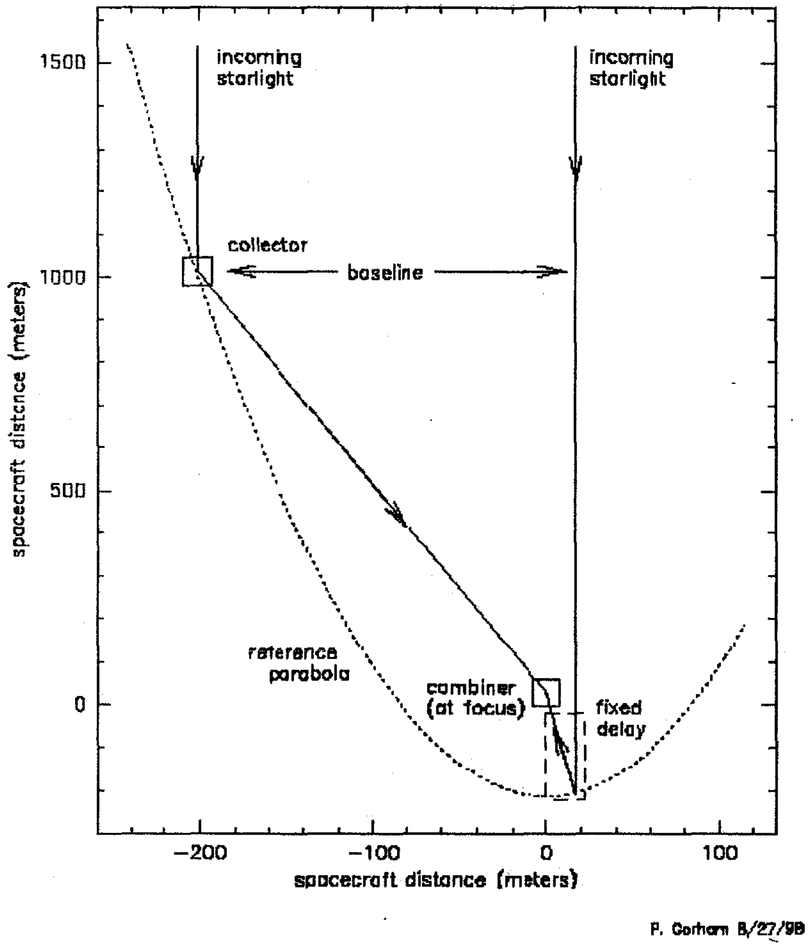


Delta 2925 Launch - September 2005
Heliocentric Earth trailing orbit

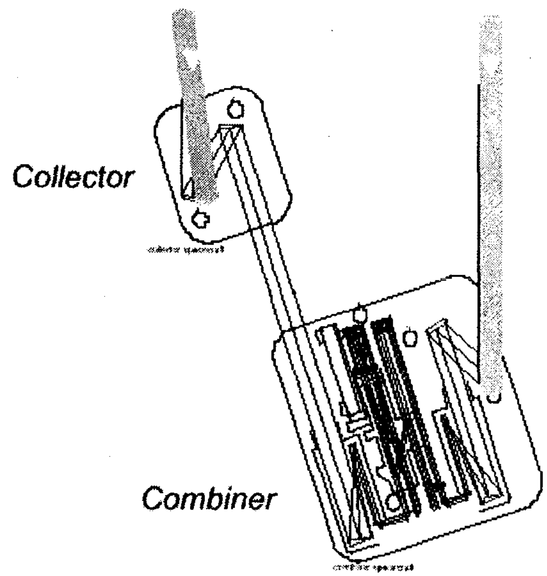
Flight System On-Orbit Configuration

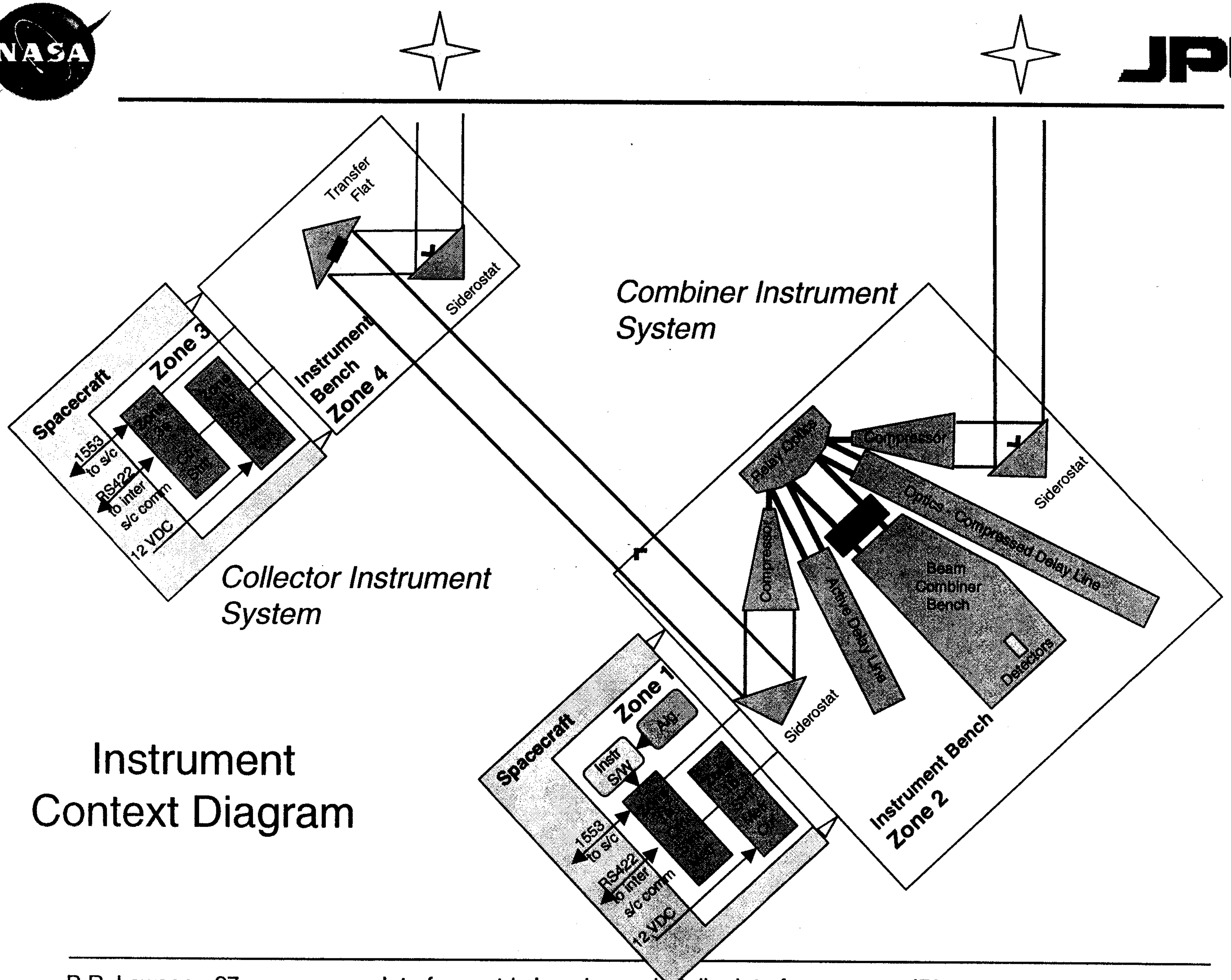


Two Spacecraft Interferometer Concept



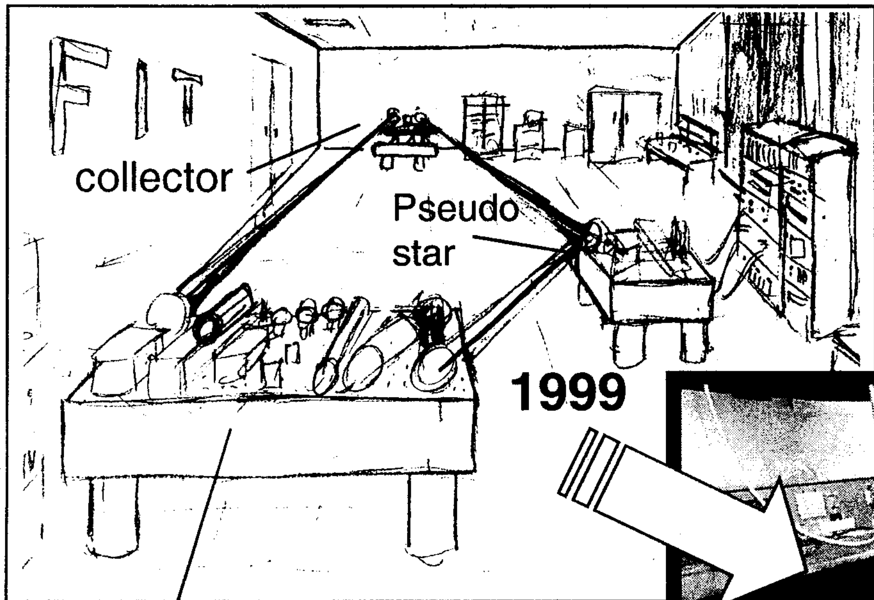
- S/C separation from 50 m to 1 km
  - Observation baselines of 40 to 200 m
  - 8th magnitude stellar targets
- Parabola is locus of constant delay
- Combiner contains 20 m fixed delay line
- Combiner can operate as a 1 m monolithic interferometer
  - No collector, bypass fixed delay





Instrument Context Diagram

Formation Interferometer Testbed

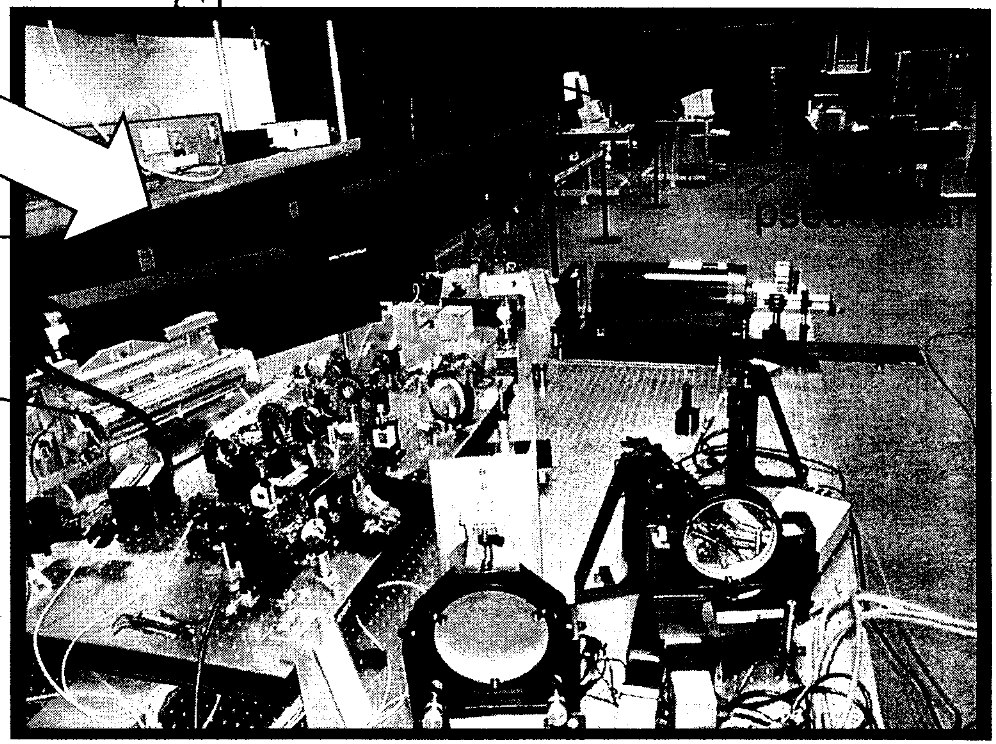


1999

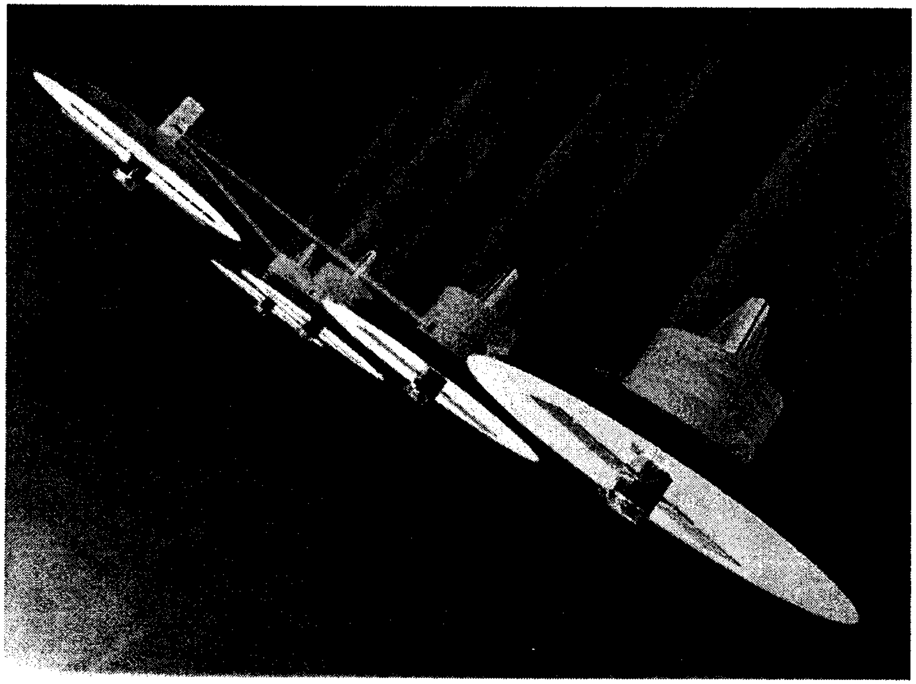
- Facility complete: cleanliness tested to < 10,000
- Breadboard H/W integrated
- Software integration in progress

Active Delay Line

Main combiner bench



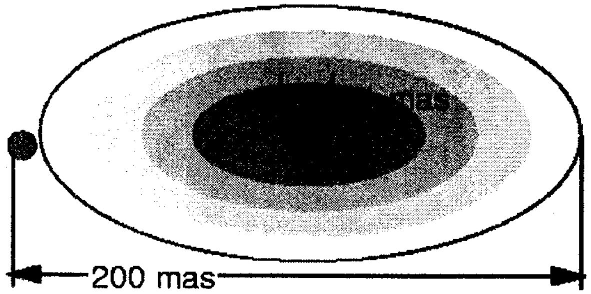
Terrestrial Planet Finder (TPF)

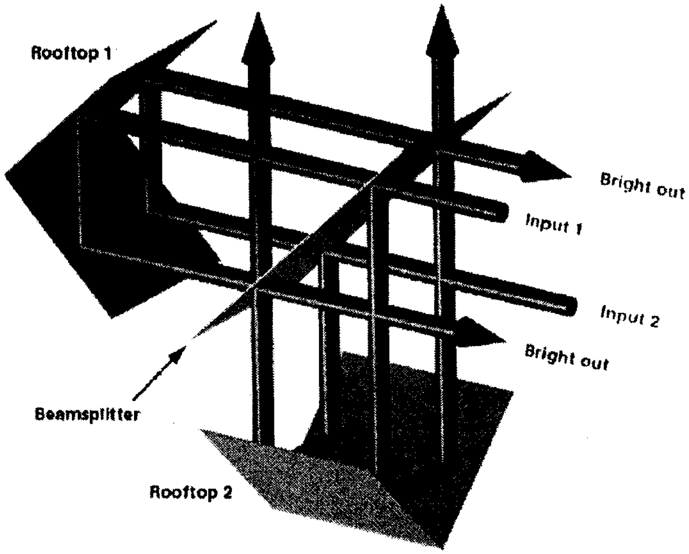


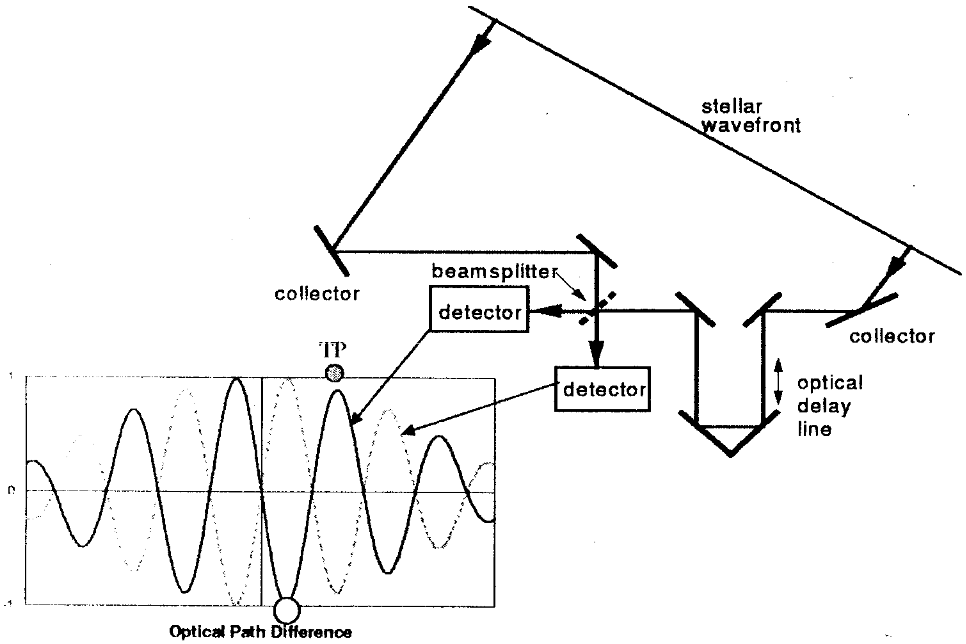
- Direct detection of Earth-like planets around nearby stars
- Approach
  - Interferometric starlight nulling by ~ 10^6 to detect 10 um infrared light from the planet
  - ~10 hrs of observation to detect an Earth-like planet at10 pc
  - 2-4 weeks to measure a low resolution spectra of the atmosphere, to identify H_2O, CO2, O3

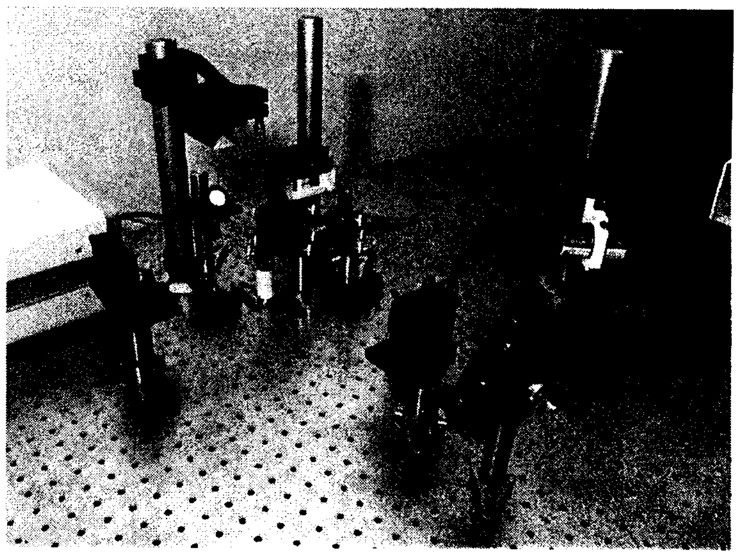
- Configuration
  - 4 large (~3m) collecting apertures
  - Cryogenically-cooled optics
  - Formation flying to provide baselines of 50 - 500 m

Nulling Interferometry







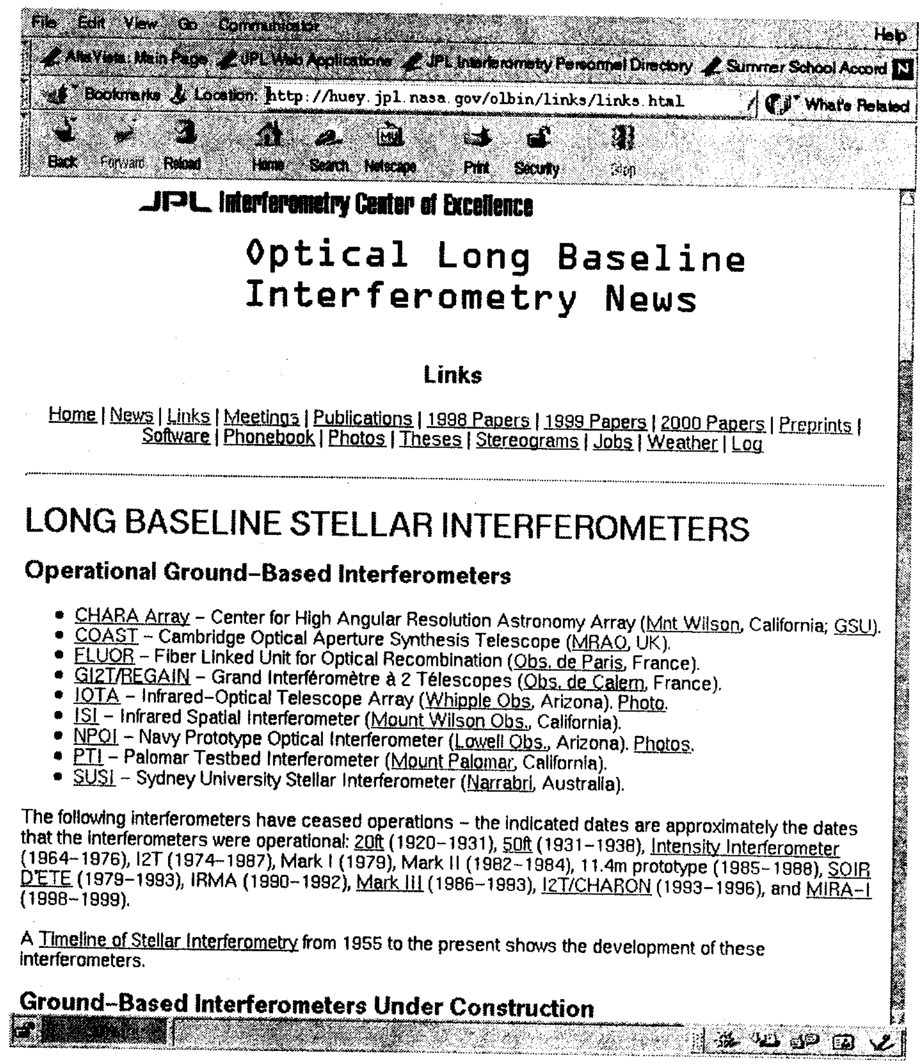


- **http://huey.jpl.nasa.gov/olbin/**

CL 99-2072

- **Contains links to all existing and proposed optical/IR interferometer projects.**

- **News**
- **Papers and preprint information**
- **Upcoming meetings**
- **Contact information**
- **Translations of selected papers**
- **List of PhD and Masters theses**
- **Photographs and resources**
- **Job listings**



Acknowledgments

Space Interferometry Mission: Michelson Fellowship Program

Terrestrial Planet Finder Preproject Office

JPL Technology and Applications Program Directorate

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